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BLAST WAVE YIELDS FOR AN EXPLOSION

by

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for the
Research Department

ABSTRACT. A blast wave overpressure-time history contains voluminous data which can be greatly simplified by converting them into equivalent yield. This calculation requires two independent parameters, usually chosen from measurements on peak overpressure, impulse, standoff distance, or travel time. Representative computations are described. Concurrence among the results of these for a particular explosion indicates a simple explosion situation and reliable data; divergence implies some effect such as focussed blast, or perhaps errors in measurement. All such information is useful in evaluation of blast wave data, and can contribute to our understanding of explosion phenomena.

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FOREWORD

This study is part of a continuing applied research program at the Naval Weapons Center in support of explosive ordnance problems and was supported by funds under the Naval Air Systems Command Task Assignment A350-350D/216F/0 F17-353-501.

Dr. Gilbert Ford Kinney, Professor of Chemical Engineering at the U. S. Naval Postgraduate School, Monterey, conducted this investigation at the Naval Weapons Center, sponsored by the Detonation Physics Division of the Research Department.

Because of the continuing nature of the explosive ordnance studies being made at the Center, refinements and modifications may later be made in the methods and the measurements discussed.

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EXPLOSIVE YIELD

The magnitude of an explosion is described by explosive yield. A representative example is description of the first nuclear explosion as equivalent to twenty thousand tons of TNT. Explosive yield serves to specify, indirectly, characteristics of the blast wave generated at different distances from the explosion. Determination of explosive yield is important in many instances; examples include evaluation of some new explosive, assessment of hazards associated with manufacture or transportation of explosives, or development of some new explosion weapon.

BLAST WAVE YIELD

An explosive yield computed from blast wave measurements is identified as a blast wave yield. Computation of a blast wave yield is the inverse of a conventional problem in the physics of explosions, one where blast wave characteristics are calculated for a specified explosion. This conventional problem has been solved theoretically for the special case of a centrally initiated bare spherical charge exploding in a uniform atmosphere, and for related situations such as a hemispherical charge exploding on an extended unyielding surface (Ref. 1 and 2). These calculated values have been adequately verified by experimental measurements (Ref. 3). These values describe a reference explosion, and form the basis for calculations of this present report.

To convert values for the reference explosion so that they describe the blast from some actual explosion, two independent parameters need be specified. Conventionally these are an explosive yield, usually expressed as a multiple of the yield of the reference explosion, and a distance from the explosion center. Also needed are a formulation of the scaling law for explosions, plus a complete mathematical description of the reference explosion. Together these items establish the entire pressure-time history for the particular blast wave system of concern. Details of the computation are described in several sources, among them Ref. 3, 4, and 5.

THREE TYPES OF BLAST OVERPRESSURE

In description of a particular blast wave system, the blast pressure item may be described in terms of either an absolute pressure or as an overpressure, the pressure above ambient. In this material we work exclusively in terms of blast overpressure, an item which in practical work may be referred to by the simple term "pressure." We should note, however, that there are three different types of blast wave overpressures corresponding to three different arrangements of the gages used for the measurement.

Simplest of these blast pressures is the free field value that exists in the undisturbed blast wave. A gage with sensing element normal to the direction of propagation of the blast (side-on to the blast front) and which also does not disturb the blast system can measure this. Thus, the phrase "side-on" commonly indicates a free field value. Results from a pencil type of blast gage offer an example. Here the physical arrangement of the gage together with its small size and pointed front give measured side-on values that can be very close to those of the free field.

Other blast gage arrangements involve face-on gages. Here the sensing element faces the explosion center and the blast impinges directly onto it. However, depending on the physical arrangement, there are two different face-on overpressures. One of these has a sensing element that is part of an extended unyielding surface which also is normal to the direction of propagation of the blast. The large unyielding surface causes the blast wave to be reflected so that the measurement is of the reflected overpressure. A face-on gage at a hard earthen surface, or perhaps one embedded in a large sheet of armor plate, can provide a reflected overpressure-time history for an impinging blast wave system.

Another type of measurement uses a face-on sensing element without the surrounding reflecting surface. Here the gage acts in the manner of one of the elements of a Pitot tube, and measures the sum of the free field overpressure and an impinging effect of the blast wind. This is termed a stagnation overpressure, implying that the measuring device has rendered the blast wind stagnate. A stagnation overpressure is necessarily greater than the free field overpressure, and is necessarily less than the reflected overpressure.

BLAST MEASUREMENT PROBLEMS

Computation of a blast wave yield requires data such as the overpressures generated at a particular location. All the various types of gages for this measurement have special problems of their own, and there are associated problems in recording instruments and interconnecting devices. One problem for the gage-connection-recorder system is response time, for the system must register pressures nearly instantaneously, yet be without overshoot. Calibration of the system is also something of a problem, perhaps more severe than sometimes realized. Calibration of the system is necessary in order to convert its output into overpressures, and ideally this calibration should be made on a time scale comparable with that of the desired measurement. Yet it is difficult to obtain pressure rise rates in a calibration device that are at all comparable with those of an explosion.

Subtle difficulties with blast measurements are also associated with details of gage placement. Thus gage orientation and type of overpressure being measured, free field, reflected, or stagnation, must be specified for the data to be meaningful. A gage with a side-on sensing element should not interact with the blast but may actually do so and cause observed values to differ from those of the free field. One troublesome source of possible interaction is the mounting for the gage, which, of course, must be sturdy, but not sufficiently large to cause a disturbance. Face-on gages are also subject to special difficulties. Thus, a gage may protrude from a surrounding surface so that the type of overpressure it measures changes from stagnation to reflection during the measurement. Alternatively, a reflecting surface surrounding a gage may be too small to block all flow; here the type of overpressure being measured changes during the measurement from that of a reflected to a stagnation overpressure. In such cases interpretation of the data is difficult.

Blast gages also are particularly sensitive to the presence of neighboring surfaces, for these can give unwanted reflections of annoying nature. This aspect may place limitations on the physical arrangement for a test, as, for example, in the vertical height of test gear or the location of support structures. Furthermore, some blast gages with associated connections are sensitive to acceleration; here motion caused by the blast can introduce error. In view of all these and other difficulties, it is only to be expected that blast overpressure-time histories ordinarily are subject to uncertainties. Some aspects of this situation are considered below.

A typical blast overpressure-time record and its required calibration are illustrated in Fig. 1.

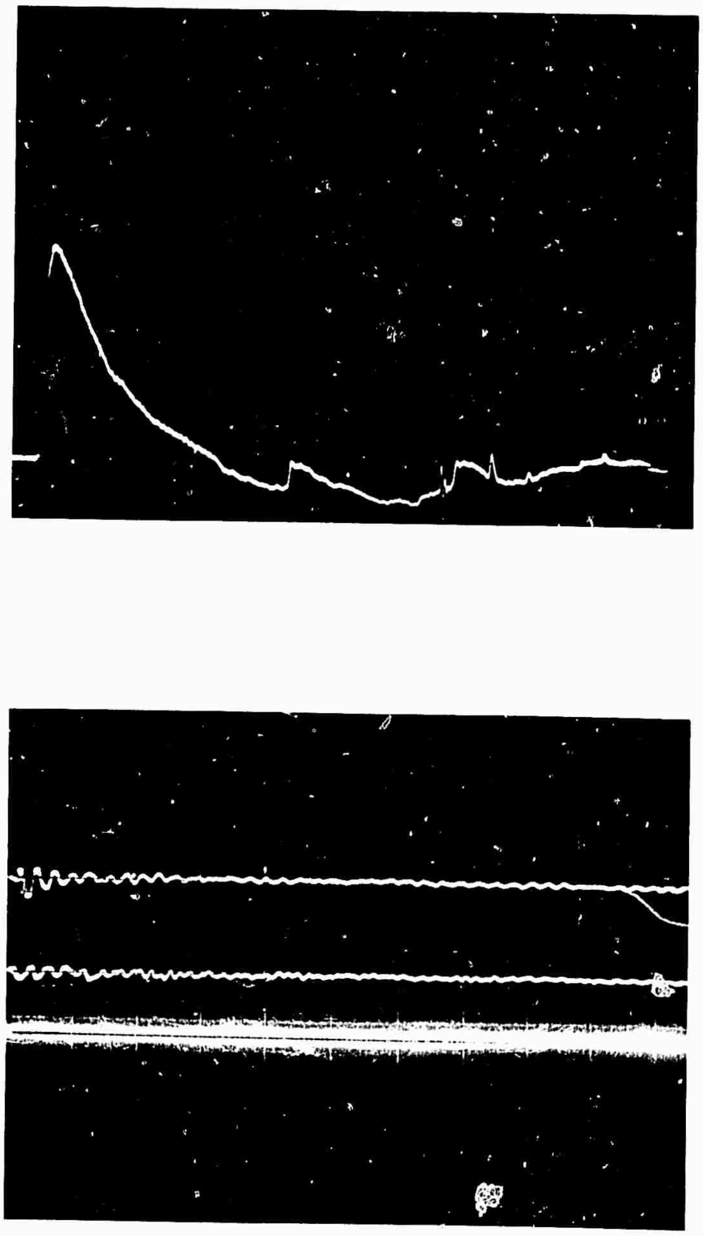

FIG. 1. Typical Overpressure-Time History and Pressure Calibration.

OVERPRESSURE-TIME HISTORY

An overpressure-time record for a blast wave contains a great deal of information about the explosion. The problem here is to organize this information into simple meaningful terms. For this it is convenient to extract from the overall record two pertinent values, (1) the peak overpressure that exists at the blast wave front, and (2) the overpressure-time integral for the initial positive phase of the blast wave system. This latter represents a positive impulse per unit area, and may be referred to by the simple term "impulse." Other items such as duration of the positive pressure phase and its rate of decay may also be of concern.

The peak overpressure for the blast wave can be found by back extrapolation of the initial portion of the record to time zero, the instant of arrival of the blast wave front (Ref. 6). This extrapolation avoids difficulty with overshoot or with finite rise time in the gage-connector-recorder system. For this purpose it is desirable to convert the analogue record as illustrated above to digital form, and then perform the extrapolation by computer. Figure 2 illustrates this conversion. Here readings taken from the analogue record and its calibration have been converted to overpressure and time, and plotted as points on semilogarithmic coordinates for the first two-thirds of the record. A straight line is then fitted by a least-squares technique. The intercept of this line gives the peak overpressure; its slope describes the decay characteristic of the blast wave. The intercept in this case indicates a peak overpressure of 58.3 psi, versus a maximum observed overpressure of 38.5 psi, and the slope, m, is -2.25 ms^{-1}. The discrepancy between peak overpressure and maximum overpressure as illustrated here is typical of a situation where a low impedance relatively slow gage system is used. This discrepancy indicates some of the possible errors associated with interpretation of blast wave data.

A parallel technique using the last third of the positive overpressure phase permits a precise identification of blast wave duration, t_d. This is illustrated in Fig. 3, where a duration is found as 1.39 ms.

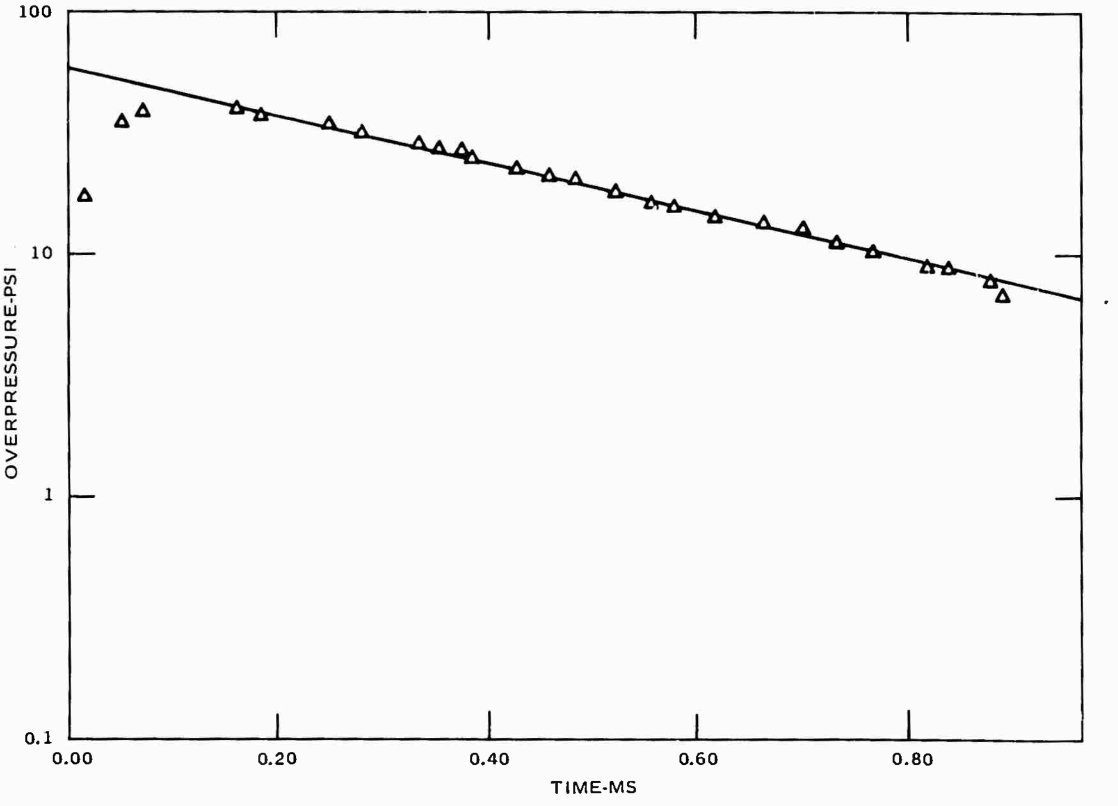

FIG. 2. Peak Overpressure Found From a Digitalized Overpressure-Time History.

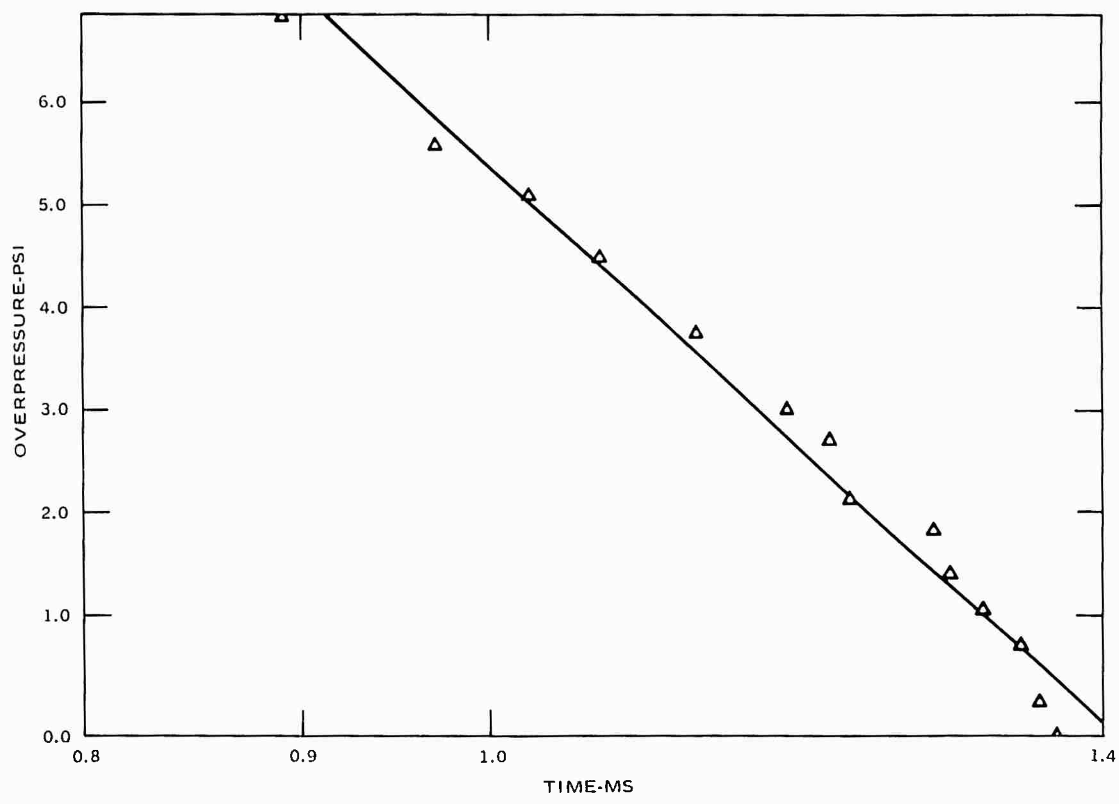

FIG. 3. Duration Time Found by Smoothing.

From results of such calculations the record for the entire positive phase of a classical overpressure-time history can be fitted to the semi-empirical equation (Ref. 3)

$$p = p^0(1-t/t_d)e^{-bt/t_d} \tag{1}$$

where p is the overpressure at time t from zero time, p^0 the peak overpressure that occurs at zero time, t_d the duration of the positive phase and e the base of natural logarithms. Here, the item b is a decay parameter related to the slope m of a previous figure and found as b = $- mt_d - 1$, and equals 2.14 for the blast wave above. Figure 4 is reconstructed from the data of Fig. 1. This shows observed values as points, and a line that corresponds to Eq. 1. General concurrence is evident. Validity of the equation and of its defining parameters can be further checked by values for impulse, that is, the overpressure-time integral. For this one compares the results of an analytic integration of the equation with those obtained by numeric integration using the original data. In this instance the impulse indicated by integration of Eq. 1 is 22.3 psi-ms, and that found by direct numeric integration is 21.4 psi-ms. Reasonable agreement such as this is to be expected in most circumstances where the blast wave configuration is classical in nature.

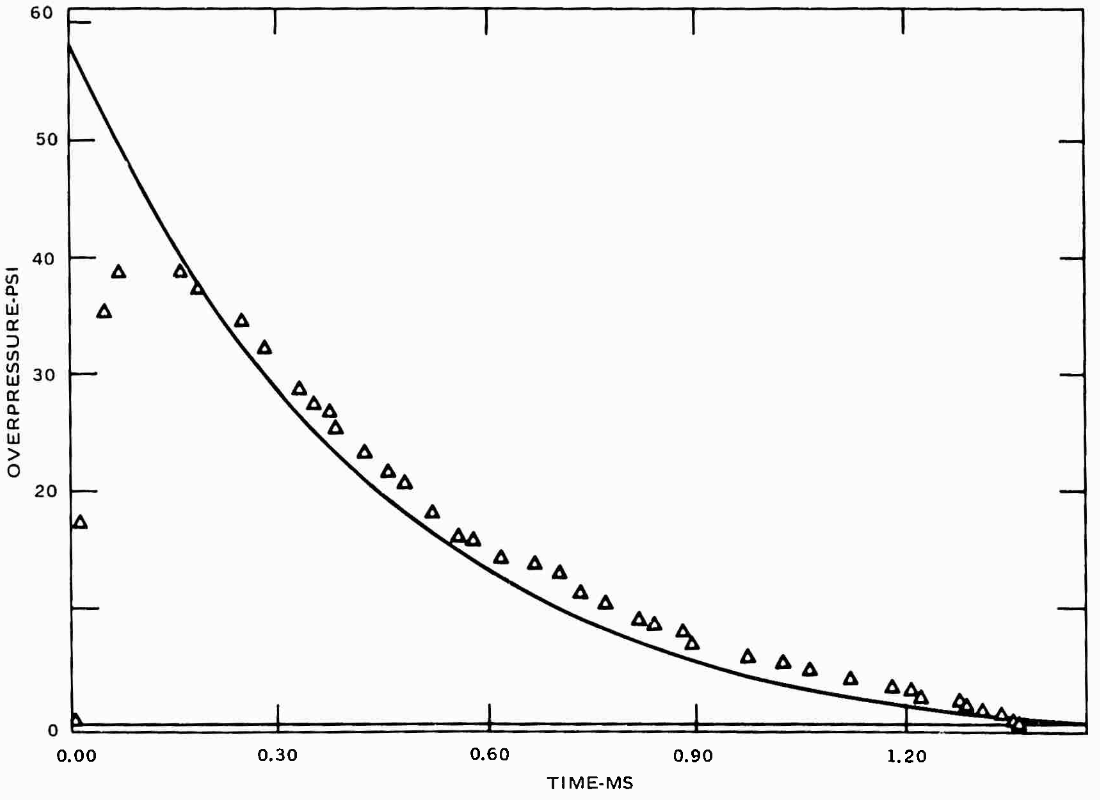

FIG. 4. Computed Decay Curve Compared With Observed Data Points.

THEORETICAL ASPECTS OF BLAST WAVE YIELD COMPUTATION

The two items obtained above, (1) peak overpressure, and (2) impulse are important for many purposes, as for example, in assessment of damage potential. In experimental studies on blast two additional items, (3) distance from center of explosion to sensing element, or standoff distance, and (4) the time interval between initiation of the explosion and arrival of the blast front at the gage, identified as travel time or as time of arrival, frequently are readily measured and provide additional useful information. An important observation concerning the four items is that only two of them are needed to establish a value for blast wave yield. This observation is consistent with item (1) above, that two independent parameters can specify a blast wave. Now there are six possible combinations of four things taken two at a time. Hence, the four items here can provide six separate estimates for the blast wave yield. If more than one gage is used for the test, then, more than one set of six estimates can be made.

A useful aspect of such multiple estimates of blast wave yield is that they permit an immediate evaluation of the internal consistency of observed data. If the estimates agree reasonably well with each other, confidence can be placed in the overall results. On the other hand, disagreement may indicate errors in measurements or in calibrations. It also may indicate a different type of explosive, or blast anomalies, such as jetting or an asymmetrical wave front, or that the configuration of the actual blast wave system differs from the classical one of the reference explosion. Disagreement may result from effects such as a blast being focussed to increase its peak overpressure without a corresponding increase in impulse, or the presence of inert material in the explosive that increases reflected impulse without a corresponding increase in side-on overpressure.

Another aspect of these blast wave yield calculations of possible interest concerns distributed energy explosions. Here there may be no definite explosion center and no definite travel time. However, overpressure-time history above, through peak overpressure and impulse, makes it quite feasible to find an effective yield. Then by inverting the yield calculation an effective standoff distance can be determined. This is illustrated by a calculation in the Appendix. Thus, in many circumstances, determination of blast wave yields can contribute both to an appreciation of the instrumentation problems in explosion tests and to our understanding of explosions and their damage potential in general.

SCALING LAW EXPRESSIONS

Determination of explosive yield from blast wave measurements is essentially an application of the scaling law for explosions. This law as used here expresses the observation that an explosion creates a disturbance by distributing energy throughout a surrounding volume, and that two disturbances are similar if they have the same geometry and if the energy release into unit amount of disturbed material is the same. Now for an explosion in a uniform atmosphere the total amount of disturbed material is proportional to its volume (cube of a distance) and also to its density. Thus, for two similar but different explosion disturbances, identified by subscripts 1 and 2,

$$W_1/W_2 = \rho_1 r_1^3/\rho_2 r_2^3 \tag{2}$$

where W is the explosive energy release, r the distance from center of the explosion to edge of the disturbance, (this distance is a function of time), and ρ is the density of the undisturbed surrounding atmosphere. This formulation of the scaling law is a modification of an earlier form (Ref. 7) that uses pressure rather than density as an index of mass.

Now consider a reference explosion with energy release W_0 into an atmosphere with density ρ_0. Let a distance from this reference explosion be termed a "scaled distance." Equation 2 now indicates that another explosion with energy release W creates a similar disturbance in an atmosphere with density ρ under conditions such that

$$\text{scaled distance} = (\text{actual distance})\ (\rho/\rho_0)^{1/3}(W_0/W)^{1/3} \tag{3}$$

This important expression is the basis for the blast wave yield calculations described here. It may be shown (Ref. 5) that it contains within it a corresponding definition of a scaled time, that is, a time interval pertaining to the reference explosion, as

$$\text{scaled time} = (\text{actual time})\ (\rho/\rho_0)^{1/3}(W_0/W)^{1/3}(a/a_0) \tag{4}$$

where a is the speed of sound, and the subscript 0 identifies a value for the reference explosion. A corresponding expression for scaled impulse becomes

$$\text{scaled impulse} = (\text{actual impulse})\ (\rho/\rho_0)^{1/3}(W_0/W)^{1/3}(a/a_0)(P_0/P) \tag{5}$$

where P indicates absolute atmospheric pressure.

These forms of the scaling relations are the inverse of conventional ones that describe an actual explosion in terms of values computed for a reference explosion.

YIELD EXPRESSIONS

Each of the last three formulations of the scaling law above can be rearranged to provide a direct solution of an actual energy release (yield) W in terms of a reference yield W_0. For this it is convenient to express the atmospheric density ratio in terms of absolute pressure and temperature, or $(\rho/\rho_0) = (P/P_0)T_0/T)$. Also the speed of sound in the atmosphere varies as the square root of its absolute temperature, or $(a/a_0) = (T/T_0)^{1/2}$. Three expressions for blast wave yield W then become

$$W = W_0(\text{actual distance/scaled distance})^3(P/P_0)(T_0/T) \tag{6}$$

$$W = W_0(\text{actual time/scaled time})^3(P/P_0)(T/T_0)^{1/2} \tag{7}$$

$$W = W_0(\text{actual impulse/scaled impulse})^3(P_0/P)^2(T/T_0)^{1/2} \tag{8}$$

These equations pertain to geometrically similar blast wave systems that create the same intensity of disturbances in their surrounding atmospheres.

The pressure and temperature ratios of the above three equations can be combined with measured values of distance, time, or impulse to give terms which are corrected for atmospheric conditions if different from those for the reference atmosphere. That is,

$$\text{corrected distance} = \text{actual distance}(P/P_0)^{1/3}(T_0/T)^{1/3} \tag{9}$$

$$\text{corrected time} = \text{actual time}(P/P_0)^{1/3}(T/T_0)^{1/6} \tag{10}$$

$$\text{corrected impulse} = \text{actual impulse}(P_0/P)^{2/3}(T/T_0)^{1/6} \tag{11}$$

These corrected items can make an apparent simplification in the equations for yield calculation. Working equations for blast wave yield W in terms of a reference yield W_0 so become

$$W = W_0 (\text{corrected distance/scaled distance})^3 \tag{12}$$

$$W = W_0 (\text{corrected time/scaled time})^3 \tag{13}$$

$$W = W_0 (\text{corrected impulse/scaled impulse})^3 \tag{14}$$

As a check on these equations, note that working Eq. 12 when combined with Eq. 9 gives the basic scaling law of Eq. 3, etc.

The fractional power terms involved in the corrected items of the above equations may in some cases be unimportant and then can be neglected. It may also be noted that each blast wave yield as computed involves the cube of a ratio, hence any uncertainty in the original measurement is magnified by a factor of three in this computation. Blast wave yields, therefore, are necessarily rather imprecise.

REFERENCE EXPLOSION DATA

The above equations are in terms of a corrected item that involves measurements on an actual explosion and a scaled item for the geometrically similar blast wave of a reference explosion. Thus, to use these relations a reasonably complete description of a reference explosion is needed. This description may be in the form of graphs, tables, or even equations; many such data are scattered through the technical literature. A fairly detailed and convenient source of data is provided by the tables of Ref. 3, and these tables are used in the calculations illustrated here. These are in English units with the explosion of a bare spherical charge of one pound of TNT in a uniform atmosphere at 13.6 psia and 59F as the reference. A second table is available for use with forthcoming metric units; this describes the explosion of one kilogram of TNT in an atmosphere at one bar (1,000 mb) and 16C (59F). The reference tables may be used directly for manual computation, as illustrated here, or they may be stored in equivalent condensed form for ready computer use.

YIELD CALCULATED FROM OVERPRESSURE AND DISTANCE

The ratio of peak overpressure to ambient pressure is a direct measure of blast wave intensity, hence the scaling law requirement for similarity is met where two different disturbances show the same overpressure ratio. This requirement for identical ratios indicates that a correction must be applied if an actual ambient pressure differs from that assumed for the reference explosion. That is,

$$\text{corrected overpressure} = \text{actual overpressure } (P_0/P) \tag{15}$$

where P_0 is the absolute atmospheric pressure for the reference explosion, and P the ambient pressure in the atmosphere of the actual explosion.

A yield calculation based on overpressure requires, in addition, data on some other item, in this case taken as a standoff distance. This, however, must be the actual distance from the center of the explosion to the sensing element, and is not quite identical with distance from charge surface to tip of a gage. A convenient routine for computation of yield using overpressure-distance data is as follows. Note that the routine requires incidental data on the pressure and temperature of the actual atmosphere.

1. Find the peak overpressure from the blast wave record, as by the extrapolation method described above.
2. Convert this peak overpressure to reference conditions by multiplying by the factor (P_0/P), as in Eq. 15.
3. Enter the table for the reference explosion at the corrected value of the peak overpressure and find a corresponding standoff distance for the reference explosion. This is the scaled distance.
4. Correct the actual distance for atmospheric pressure and temperature, as by Eq. 9. This gives the corrected distance.
5. Compute yield as the cube of the ratio (corrected distance/scaled distance), as by Eq. 12.

The reference overpressure used in this calculation must be of the same type as that for the actual explosion, that is, free field reflected, or stagnation. Both free field and reflected values are provided directly in reference tables. For the less frequently used stagnation overpressure the most convenient procedure seems to be to convert to free field values. Formulas and tables that provide for this conversion are given in Ref. 5.

The five steps of the calculation above are illustrated using data for the explosion whose overpressure-time history is shown in Fig. 1 through 4, and for which other data are given in the Appendix.

Step 1. The determination of peak overpressure from the overpressure-time history is illustrated in Fig. 2. This peak overpressure is found to be 58.3 psi.

Step 2. By Eq. 9, correct peak overpressure = 58.3 × (13.6/13.6) = 58.3 psi.

Step 3. Entering the table of Ref. 3 at a peak reflected overpressure of 58.3 psi, the corresponding scaled distance is seen to be between 5.60 and 5.65 feet. Linear interpolation, adequate for purposes here, indicates a scaled distance of 5.64 feet.

Step 4. Corrected standoff distance = $5.50 \times (13.6/13.6)^{1/3}$ $(59+460)/(102+460)^{1/3}$ = 5.36 feet.

Step 5. Yield = $(5.36/5.64)^3$ = 0.86 pounds TNT.

YIELD CALCULATED FROM OVERPRESSURE AND TRAVEL TIME OR IMPULSE

A yield calculation using overpressure with travel time rather than with standoff distance is quite similar to the calculation above, except of course, that Eq. 10 and 13 involving time are used rather than those involving distance. Calculation of yield from overpressure and impulse also proceeds in a similar manner. The Appendix includes the results of these plus other calculations of blast wave yield.

YIELD CALCULATED FROM STANDOFF DISTANCE AND TRAVEL TIME ONLY

Yield calculation using overpressure are straightforward in that they permit direct entry into a reference table. Where only standoff distance and travel time are to be the basis for a yield calculation, such direct entry may not be possible. This difficulty can readily be circumvented, however. Thus, by combining working Eq. 12 and 13 it can be seen that the ratio (corrected distance/corrected time) is identical with the ratio (scaled distance/scaled time). This ratio has the physical meaning of average travel speed, and also is a measure of explosion disturbance intensity. A technique for computation of yield using such data is as follows.

Step 1. Correct standoff distance for ambient pressure and temperature, as by Eq. 9, and travel time as by Eq. 10. Divide the first by the second to find the corrected (distance/time) ratio. This is also the scaled ratio.

Step 2. Enter the table describing the reference explosion at the computed (distance/time) ratio, and find a corresponding scaled distance.

Step 3. Compute blast wave yield as the cube of the ratio (corrected distance/scaled distance), as by Eq. 12.

An alternative procedure is to find scaled time in Step 2 rather than scaled distance, and then compute yield as the cube of a time ratio. The two procedures give identical results.

A convenient circumstance for the above calculation is that the tables of Ref. 3 provide directly the needed values for the average travel speed for the blast wave of the reference explosion. If tables without this item are to be used, it can readily be provided by simple division of tabulated distance by tabulated time.

YIELD CALCULATED FROM IMPULSE-DISTANCE AND FROM IMPULSE-TIME DATA

Computing a yield using only impulse-standoff distance data has a difficulty mentioned above; there may be no means for ready entry to the table that describes the reference explosion. However, by combining Eq. 12 and 14 it can be seen that the ratio (corrected impulse/corrected distance) is identical with the ratio (scaled impulse/scaled distance). A computational technique based on this observation is as follows.

Step 1. Correct impulse and standoff distance for atmospheric pressure and temperature, as by Eq. 9 and 11. Then find the ratio of these. This also is the ratio (scaled impulse/scaled time).

Step 2. From individual tabulated values for impulse and for distance in the table for the reference explosion, prepare a supplemental column of (impulse/distance) ratios. Enter this column with the ratio of corrected values found in Step 1, and note the corresponding scaled distance.

Step 3. Compute yield as cube of the ratio (corrected distance/scaled distance).

A parallel routine using data for impulse and for travel time permits a separate yield computation, for by Eq. 13 and 14 the ratios (corrected impulse/corrected travel time) and (scaled impulse/scaled travel time) are identities.

In all these calculations it is important to know the type of impulse measured, whether free field, reflected, or stagnation, and to use corresponding values for the reference explosion. It should also be noted that relatively few descriptions of the blast wave for a reference explosion include all these individual impulse items.

COMPUTER CALCULATIONS

The above yield computations, including extraction of peak overpressure and determination of observed impulse, can all readily be performed by computer. A program using digitalized data in punched-card form has been prepared for this purpose, and its use is indicated for routine or repetitive calculations.

Appendix

TYPICAL CALCULATIONS

1. MEASURED CONDITIONS OF TEST EXPLOSION

ambient pressure	13.6 psia
ambient temperature	102 F
standoff distance	5.50 ft
travel time	1.71 ms

Obtained From Overpressure-Time History (Reflected Values)

peak overpressure	58.3 psi
impulse	21.4 psi-ms

Corrected to Reference Conditions of 59F and 13.6 psia

corrected peak overpressure	58.3 psi
corrected standoff distance	5.36 ft
corrected travel time	1.69 ms
corrected impulse	21.1 psi-ms

Computed Yields (pounds TNT) based on:

peak overpressure and standoff distance	0.86
peak overpressure and travel time	0.83
peak overpressure and impulse	1.07
standoff distance and travel time	0.86
impulse and standoff distance	0.92
impulse and travel time	0.98
average	0.92
standard deviation	±0.06

The concurrence illustrated is representative of reasonably good measurements made under field conditions.

2. ANALYSIS OF BLAST FROM A FUEL-AIR EXPLOSION

The overpressure-time record made at the surface of the earth during an overhead fuel-air explosion indicated a peak reflected overpressure of 245 psi and a positive reflected impulse of 210 psi-ms. Assume atmospheric pressure and temperature close to those of the reference explosion so that correction may be neglected and find the indicated yield and the equivalent standoff distance.

This peak reflected overpressure corresponds, by the tables of Ref. 3, to a scaled reflected impulse of 42.3 psi-ms. Then by Eq. 14,

$$\text{indicated yield} = (210/42.3)^3 = 130 \text{ pounds TNT}$$

This observed peak overpressure also indicates a scaled distance of 3.65 feet. By Eq. 3, when inverted

$$\text{actual distance} = 3.65\ (130)^{1/3} = 18.5 \text{ feet}$$

That is, this distributed energy explosion is equivalent at this particular location to the concentrated energy explosion of a bare spherical charge of 130 pounds of TNT directly overhead at a height of 18.5 feet.

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13. ABSTRACT

A blast wave overpressure-time history contains voluminous data which can be greatly simplified by converting them into equivalent yield. This calculation requires two independent parameters, usually chosen from measurements on peak overpressure, impulse, standoff distance, or travel time. Representative computations are described. Concurrence among the results of these for a particular explosion indicates a simple explosion situation and reliable data; divergence implies some effect such as focussed blast, or perhaps errors in measurement. All such information is useful in evaluation of blast wave data, and can contribute to our understanding of explosion phenomena.

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